Chapter 5

Fuel Utilization During Exercise

Slides developed by:
Richard C. Krejci, Ph.D.
Professor of Public Health
Columbia College
9.19.14
What You Will Learn in this Chapter

- Ways that fuel utilization can be measured in laboratory
- Patterns of fuel utilization during exercise & factors that affect it
- Physiologic objectives of fuel utilization
Foundation for our current knowledge of fuel utilization can be found in work of three pioneering figures in field of chemistry:

1. Joseph Priestly
2. Antoine Lavoisier
3. Pierre-Simon Laplace
Joseph Priestly

- In 1767, he identified Carbon, or graphite, could conduct electricity
- In 1772 & 1773, he identified:
  - “Heavy gas” was consumed by plants
  - Plants sustain life by producing “dephlogisticated air”
- The process of converting carbon dioxide into sugar is now known as photosynthesis.
Antoine Lavoisier

- Developed system of “chemical nomenclature” in 1789
  - Forms basis for development of periodic table

- Lavoisier named Priestley’s
  - “Heavy gas” carbon dioxide (CO₂)
  - “Dephlogisticated air” oxygen (O₂)

- Finally, Lavoisier established
  - Law of conservation of mass
  - Listed light & heat emitted from a reaction as substances & named them “light” & “caloric”
Pierre-Simon Laplace

- Used a calorimeter to:
  - Estimate heat evolved per unit of CO$_2$ produced in a reaction involving O$_2$

- He reported value as:
  - Calories

- Notably, these discoveries are fundamental basis of our current investigations into human body’s energy metabolism
  - At rest
  - During exercise
  - Disease
Quantitative Measurements of Fuel Metabolism

- **Energy substrates**
  - In any biological system, nutrients that yield ATP

- **Arteriovenous difference technique**
  - Uses amount of a molecule entering & leaving an organ or tissue bed to calculate production or release of a molecule

- **Isotopic approaches**
  - These have many applications
  - Isotopes are used in exercise physiology research to calculate flux of energy substrates in & out of bloodstream
Quantitative Measurements of Fuel Metabolism

- **Indirect calorimetry**
  - A method by which oxidation of CHO & fats are calculated from
    - Rate of uptake of $O_2$ & rate of $CO_2$ production
    - Accurate application of this method requires an *estimate of protein oxidation*
Quantitative Measurements of Fuel Metabolism

- **Pulmonary gas exchange**
  - Movement of $O_2$ from environment to pulmonary circulation
  - Movement of $CO_2$ from pulmonary circulation to environment
  - Process requires bulk flow of air into lungs & diffusion of gases between air & blood

- **Muscle biopsy**
  - A muscle sample obtained to measure composition of muscle
Three Principles of Substrate Utilization during Exercise

- The contribution of CHO, fat, & protein to metabolic demand of working muscle depends on different factors relating to:
  - **Subject characteristics**
    - Fitness
    - Nutritional state
    - Specific health deficits
  - **Environmental conditions**
    - High altitude
    - Temperature extremes
Factors that Affect Metabolic Response to Exercise

- Intensity of Exercise
- Duration of Exercise
- Level of Personal Fitness
- Exercise Mode
- A Specific Pathology
- Exercise Environment
- Nutritional Factors
Three Principles of Substrate Utilization during Exercise

- Most important determinants of type & amount of fuel used are:
  - Exercise duration
  - Exercise intensity

Objectives of substrate metabolism during exercise:

1. Maintain glucose homeostasis
2. Metabolize most efficient substrate
3. Spare muscle glycogen

- Failure to accomplish any of these will
  - Impair work performance
  - Inability to exercise further
Preserving Glucose Homeostasis

- **First objective of substrate metabolism**
  - Maintain glucose homeostasis (blood and muscle glycogen levels)

- **Primary reason**
  - Brain is reliant on glucose metabolism for energy except under unusual conditions

- **Blood glucose homeostasis may be compromised under certain exercise conditions**
  - High intensity exercise
  - Prolonged exercise (> 90 min)
Preserving Glucose Homeostasis

- Ingestion of glucose can
  - Correct or prevent decrease in blood glucose
  - Increase capacity for prolonged exercise
Metabolizing the Most Efficient Substrate

- **Second objective of substrate metabolism**
  - Metabolizing most efficient substrate
- Depending on intensity of exercise, fuel used results in
  - Different rates and amounts of energy yield
Metabolizing the Most Efficient Substrate

- During high intensity exercise
  - Need is for most *metabolically-efficient* (more ATP per \( \text{O}_2 \)) fuel

- During light exercise, which can be maintained for a long time
  - Need is for most *storage-efficient* (more ATP per substrate mass) fuel
Reasons for these Intensity-Related Differences

- During high intensity exercises
  - ATP utilization is more rapid & $O_2$ supply can be limited
- Under these conditions CHO is
  - more *metabolically efficient* than is fat
  - better suited to the needs of high intensity exercise
- Why?
Reasons for The Intensity-Related Differences

- CHO is broken down without $O_2$ to produce ATP from glycolysis
  - Occurs at a much higher rate than mitochondrial ATP production by oxidative phosphorylation

- Utilization of both blood glucose & muscle glycogen increases with exercise intensity
  - With increments being largest at the highest work rates
Efficiency of “Fuels” in Relation to Exercise Intensity and Duration

- **Metabolic Efficiency**
  - Carbohydrates are the preferred energy source during high intensity work because its metabolism yields more energy per liter of oxygen than with fat metabolism
    - Anaerobic glycolysis- no oxygen (O$_2$) is required.
    - Complete CHO oxidation – 5.05 kcals/liter O$_2$
    - Oxidation of fat – 4.74 kcal/liter O$_2$

- **Storage Efficiency**
  - Fat is the preferred energy source during prolonged bouts of exercise because its metabolism provides more energy per unit mass than CHO metabolism
    - CHO oxidation – 4.10 kcal/gm fuel
    - Fat oxidation – 9.45 kcal/gm fuel
  - Fats are stored in the absence of H$_2$O enhancing storage efficiency

Table 5.2 p. 134
Glycogen Utilization with Increased Exercise Intensities

Figure 5.2 p. 134
Glucose Uptake During Cycling

![Graph showing glucose uptake by the working limb in mmol/min vs. whole body oxygen uptake in ml/min.]

Figure 5.3 p. 135
Metabolizing the Most Efficient Substrate

- **In contrast, fat**
  - Most *storage-efficient* fuel
  - Used during light exercise that can be sustained for long intervals

- **Under these circumstances**
  - Speed & efficiency of ATP formation are *secondary* to fuel storage efficiency

- **Differences in degree of saturation of FFA & glucose carbons predict**
  - Twice energy can be gained from oxidation of triglycerides than an equal quantity of glycogen
# Energy Metabolism from Glucose and FFAs

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Substance Processed</th>
<th>Location</th>
<th>Energy Yield (per glucose molecule processed)</th>
<th>End Products Available for Further Energy Extraction</th>
<th>Need for Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycolysis</td>
<td>Glucose</td>
<td>Cytosol</td>
<td>2 molecules of ATP</td>
<td>2 pyruvic acid molecules</td>
<td>No; anaerobic</td>
</tr>
<tr>
<td>Tricarboxylic acid cycle</td>
<td>Acetyl-CoA, which is derived from pyruvic acid, the end product of glycolysis and beta-oxidation of acyl-CoA derived from free fatty acids</td>
<td>Mitochondrial matrix</td>
<td>2 molecules of ATP</td>
<td>8 NADH and 2 FADH$_2$ hydrogen carrier molecules</td>
<td>Yes, derived from molecules involved in tricarboxylic acid cycle reactions</td>
</tr>
<tr>
<td>Electron transport chain</td>
<td>Glucose</td>
<td>Cytosol</td>
<td>32 molecules of ATP</td>
<td>None</td>
<td>Yes, derived from molecular oxygen acquired from breathing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mitochondrial inner-membrane cristae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mitochondrial matrix</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sparing Glycogen Stores

- **Third objective of substrate metabolism**
  - Spare glycogen

- Ability for healthy subjects to perform high intensity and long duration exercise is limited by:
  - Cardiovascular (CV) system
  - Possibly by the respiratory track (lungs and airways)

- Glycogen depletion is a likely cause of fatigue
  - During prolonged exercise
Sparing Glycogen Stores

- There is a close relationship between
  - Depletion of muscle glycogen stores
  - Time to exhaustion during moderate exercise
- Maintaining a high-CHO diet that promotes glycogen stores
  - Increases capacity to perform prolonged exercise
Intramuscular, Blood Glucose and Blood FFAs Utilization vs. Exercise Duration

Figure 5.4  p. 136
Conserving Muscle Glycogen

Other fuels are utilized to spare glycogen during prolonged exercise thereby delaying exhaustion.

As exercise duration increases:
- More energy is derived from fats and less from glycogen.
- Amino acid, glycerol, lactate, and pyruvate carbons are recycled into glucose.
Sparing Glycogen Stores

- From Proteins
  - Branched-chain AA
    - (leucine, isoleucine, & valine)

- From Fatty-acids
  - Ketone body oxidation
    - (Acetone, acetoacetate, & beta-hydroxybutyrate)
    - Increase with prolonged exercise
    - May play a small part in sparing muscle glycogen
Give and Take of Fuel Metabolism during Exercise

- All 3 objectives of substrate metabolism are
  - Generally achieved during light-to-moderate exercise of 90 minutes or less
    - As long as subjects are healthy
- One objective is compromised to achieve another when a person
  - Attempts to test his or her exercise limits
- For example: during very intense exercise
  - Muscle glycogen & blood glucose are used at high rates because of requirement for a metabolically efficient fuel
Give and Take of Fuel Metabolism during Exercise

- Sustained high rates of muscle glycogen utilization
  - Cannot be sustained without depleting their stores
- Liver can normally replenish blood glucose as it is used
- As duration of exercise increases
  - Liver glycogen becomes depleted
  - Because gluconeogenesis alone is inadequate at maintaining blood [glucose] levels
    - A constant low blood sugar (hypoglycemia) results
Muscle Glycogen vs. Exercise Duration

Figure 5.6  p. 140
<table>
<thead>
<tr>
<th>Lauren</th>
<th>Glucose homeostasis?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Which is more efficient: CHO or fats?</td>
</tr>
<tr>
<td></td>
<td>Weight loss?</td>
</tr>
</tbody>
</table>

By understanding fuel utilization, what can you now tell your client about…
Carla Medical weight-loss programs?

By understanding fuel utilization, what can you now tell your client about…
In Practice: Athletic Performance

Kelsey and Sharlise

Optimal training?
What to consume prior to competition?

By understanding fuel utilization, what can you now tell your athlete about…
In Practice: Rehabilitation

<table>
<thead>
<tr>
<th>Jasmine</th>
<th>Diabetes?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>How to use of insulin &amp; its effect on blood [glucose]?</td>
</tr>
<tr>
<td></td>
<td>How to prevent insulin shock?</td>
</tr>
<tr>
<td></td>
<td>How to prevent diabetic coma?</td>
</tr>
</tbody>
</table>

By understanding fuel utilization, what can you now tell your client about…
Practical Applications (Fuel Utilization)

- Reinforce consistent and healthy nutritional patterns in clients/athletes
- Appropriate advice to clients engaged in weight loss and weight maintenance programs
- Appropriate advice for an athlete’s pre-event meal planning
- Understand the basics of control of blood glucose concentrations in diabetes to prevent insulin shock (severe hypoglycemia) or diabetic coma (ketoacidosis)
The End

Slide Show was prepared by:
Richard C. Krejci, Ph.D.
Professor of Public Health
All Rights Reserved